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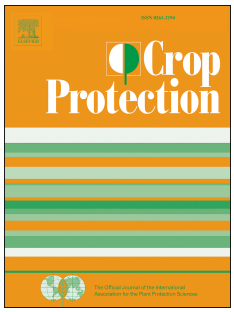

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Editorial: Impacts of COVID-19 on global plant health and crop protection and the resulting effect on global food security and safety

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1. Introduction

Agriculture, in general, is an input-intensive sector. Key agricultural inputs include fertilizers, plant protection products (PPPs; that include conventional and bio-pesticides or any other beneficial arthropod used for inundative and inoculative biological control, including bees for pollination), seeds, fuel and labor. Disruptions in the supply and availability of these inputs are likely to result in reductions in outputs. However, these reductions depend on how much a given cropping system is dependent on these inputs (e.g. organic farming and agroecological cropping systems are less dependent on synthetic inputs compared with conventional systems, but can be more labor intensive). The production, choice, purchase and application in a timely manner of these inputs are widely affected both at the upstream and downstream level by the COVID-19 pandemic leading to severe consequences in the agricultural sector.

More specifically to the crop protection sector, crop losses due to pests (*sensu lato* that includes animal pests, pathogens and weeds) may reach up to 80% (Oerke, 2006). Crop losses caused by crop pathogens alone cost the global economy USD220 billion annually (Savary et al., 2019). These losses may be prevented, or contained, by implementing crop protection measures including cultural (cultivar choice, crop rotation, tillage, mechanical weeding, etc.), biological (parasitoids, predators, etc.) and chemical measures (biopesticides and synthetic pesticides). Continuous monitoring and management of pests are critical for sufficient quantity and quality of harvest. A set of preventive and curative actions often needs to be taken to protect crops from pests, based on a sequential rationale of the eight principles of integrated pest management (IPM; Barzman et al., 2015). These principles should be applied in a timely manner at different stages from pre-sowing to post-harvest of a given crop. Any disturbance in these interventions may lead to irreversible losses at different stages of a crop cycle thereby altering the quantity and quality of a harvest itself with a huge burden on food security and safety, respectively.

This editorial aims to highlight key short- to medium-term impacts of the COVID-19 pandemic and the measures applied to combat it (e.g. restricting the movements of people and materials via lockdowns, travel restrictions, border closures, confinement, curfews or quarantine measures) on crop protection that may affect current and near-future harvests.

2. Direct and indirect short to medium-term impacts of the COVID-19 pandemic on crop protection

2.1. No or limited supply and/or availability of plant protection products

Lockdown and quarantine measures applied to combat the COVID-19 pandemic have limited the production and supply of PPPs thereby affecting crop protection activities worldwide. Evidence shows a surge in demand for PPPs due to individuals and groups ordering more stock than they would normally. This will further hamper availability of PPPs on the market. For example, in China, a country affected at an early stage of the pandemic, the production of PPPs declined sharply and only resumed gradually after production plants were shut down following the outbreak (http://news.agropages.com/News/NewsDetail---34690-e.htm). Because China is one of several key producers and suppliers of PPPs to many developed and developing countries, the COVID-19 pandemic may affect the availability or lead to a rise in prices of PPPs worldwide. This may have an important impact on crop protection and yields, especially across high-income countries that are more exposed to disruptions in input supplies for their agricultural production processes compared with low-income countries (Schmidhuber et al., 2020). For example, grain and oilseeds production in the EU, the USA or Canada, largely depend on these inputs, notably fuels, seeds, fertilizer and pesticides.

The disruption caused by the COVID-19 pandemic in the flow of PPPs, either from local or international suppliers to the farm level, has already resulted in reduced outputs (Brewin, 2020; Schmidhuber et al., 2020). For instance, transportation costs of pesticides to East Africa have increased by a factor of three and shipping was delayed due to fewer flights to the region (https://www.bloomberg.com/news/articles/2020-03-22/coronavirus-slowing-desert-locust-response-in-east-africa). This has in turn limited Eastern African countries' ability to readily control locusts that has resulted in record-setting waves of swarms in this region with serious pest outbreaks (Schmidhuber et al., 2020). The lack of an immediate response to control locusts in East

Africa has further triggered the migration of more swarms that have dramatically afflicted parts of Kenya, Yemen, Pakistan, India and even Nepal with some of the swarms that were the largest seen in several decades. Another example is the lack of effective management of fall armyworm, a polyphagous pest that threatens food security worldwide (Early et al., 2018), due to disrupted distribution and application of PPPs caused by the COVID-19 pandemic (FAO, 2020). Approval and distribution of genetically engineered crops expressing insecticidal toxins has also been affected by the COVID-19 pandemic. Transgenic cowpea expressing Bt toxins was approved in December 2019 for commercial use in Nigeria. However, restrictions in movement of people due to the pandemic has considerably slowed the distributions of seeds to farmers (Isaac 2020), which may lead to a delay in the adoption of Bt cowpea, with consequences for food security.

Although no disease outbreaks due to the COVID-19 pandemic are yet reported, due to the microscopic nature of pathogens, plant epidemics may have been spreading silently, affecting crop yields and the global economy (He and Creasey Krainer, 2020). Although no economic estimation of crop losses due to pests during the pandemic has been made yet, devastating effects may have already occurred.

2.2. Lack of timely crop protection interventions due to shortage of labor and spray operators

Low-income countries that have labor-intensive agricultural systems may find their supply chains disrupted and outputs compromised due to labor shortages owing to the COVID-19 pandemic. This is mainly due to direct health effects or indirect effects of shutdowns. However, high-income countries have also faced labor shortage problems such as those of spray operators or seasonal labor requirements for planting vegetables

and harvesting fruits, as already is the case in the United States and in several EU countries such as France, especially in the horticultural sector. However, even row crops that are typically less labor intensive have been impacted (https://www.reuters.com/article/us-health-coronavirus-usa-wheat/u-s-farmers-scramble-for-help-as-covid-19-scuttles-immigrant-workforce-idUSKBN2431BQ). This means that labor shortage effects occur across both high and low-income countries and that they are sector-specific rather than country-specific.

A reduced availability of agricultural labor may occur through multiple mechanisms including illness that reduces physical capacity, aversion behaviour and quarantine restrictions (Schmidhuber et al., 2020). In this situation, farmers might not be able to perform crop protection interventions including mechanical weeding and timely pesticide sprays. This may affect both preventive (e.g. no or reduced pest monitoring and early warnings) and curative (e.g. pesticide sprays) pest management actions leading to severe crop losses. There is evidence that IPM activities -- such as field activities for pest management, capacity development initiatives etc. -- have already been affected by the COVID-19 pandemic (FAO, 2020).

For inundative biological control, farmers' pest management strategies rely on regular introductions of beneficial insects and mites that are live animals with a short shelf life. The logistics to supply these animals depends on rapid transit across borders, and on logistics running effectively. Staff shortages will interrupt logistics and lead to some shortages and delays. Although no data are yet available in this regard, we can expect significant yield losses due to the lack of timely crop protection interventions owing to labor shortage during the COVID-19 pandemic.

2.3. Lack of timely crop protection interventions due to financial constraints

Even in the absence of labor shortage, farmers may either not have access to bank loans or may not be willing to purchase pesticides to protect their crops. This may particularly be the case in developing countries where famers may save money for eventual household healthcare issues that may be either directly or indirectly aggravated by the COVID-19 pandemic. In the absence of prompt crop protection interventions, there might be two major types of crop losses in terms of: i) quality, because the visual aspect of agricultural products may be jeopardized that renders them unmarketable, and ii) quantity, because in the absence of timely protection interventions, pests will attack crops and reduce yields.

2.4. Lack of timely crop protection interventions due to equipment shortage

A shortage of certain types of equipment, such as fogging equipment that is currently in high demand for disinfectants to reduce the spread of COVID-19, may affect the crop protection sector. This equipment is used for crops such as potatoes, to apply sprout suppressants in storage (Paul et al., 2016). Shortages due to COVID-19 have also impacted the availability of respiratory protective equipment for agricultural workers handling pesticides, which has been reported in the United States (U.S. Environmental Protection Agency [EPA] 2020). This has led to a number of temporary recommendations from the U.S. EPA, including reusing N95 respirators, using expired respirators, applying pesticides that do not require respirators, and delaying pesticide applications. Clearly, this is leading to increased risks for the applicator as well as increased crop damage due to suboptimal applications.

2.5. Impacts on training and certification programs

According to the EU Sustainable Use Directive, all professional users of PPPs (those involved in the recommendation, sale, purchase and application of PPPs) must obtain an

individual certificate (European Commission, 2009a), with similar certification programs in other developed countries. While it is not currently possible to assess the impact of the COVID-19 pandemic on training and certification programs, several lockdown and quarantine measures might have caused temporary disruption of these programs. In the United States, the U.S. EPA has allowed states to make temporary changes to training and certification programs for pesticide applicators, including relying on remote testing and extending certification periods. In addition, capacity development and awareness raising programs have already been affected by the COVID-19 pandemic, as reported for IPM activities of fall armyworm (FAO, 2020). Delivery of traditional extension programs from crop protection specialists (from both public and private sectors) have had to shift from in-person meetings with farmers, consultants, and other agricultural professionals to mainly remote training programs. While in the long term, this may lead to more effective and immediate online training programs as a complement to in-person meetings, this immediate disruption could potentially hinder the transfer of technology from research and development to the end-users. Adoption of the most up-to-date pest management practices may therefore be delayed or curtailed as a result of this shift in delivery methods.

2.6. Active ingredient approval and authorization process of plant protection products

The authorization process prior to approving any PPP is generally lengthy and requires a lot of interactions between the manufacturer and regulatory authorities of a country. This is particularly the case in the EU following the Regulation 1107/2009/EEC on placing of PPPs on the market (European Commission, 2009b). This process might be slowed down due to the COVID-19 pandemic.

2.7. Delays in research activities at public universities and institutes

As countries deployed lockdown measures to slow the spread of COVID-19, many universities and research institutes were forced to scale back, delay, or cancel research activities (Servick et al. 2020), including research related to crop pests and their management. For example, agricultural research institutes in Kenya, Uganda, and Tanzania were forced to restrict or cancel activities such as research trials, stakeholder surveys, field days, and undergraduate and graduate student training (Makoni 2020). As universities reopen after lockdowns, outbreaks of COVID-19 on campuses in the United States are disrupting teaching activities, with potential for research activities to also be impacted. The pandemic may therefore lead to delays in both the development of novel pest management tactics and the training of students that may enter the workforce in agriculture and pest management.

3. Impacts on plant health

The COVID-19 pandemic may have affected a range of measures needed to ensure plant health. They include quarantine measures, implementation of plant health regulations, especially those related to plant passporting requirements. In addition, emergency authorization processes, needed to contain quarantine pests, may have been affected, yet the urgent threat of such pests requires a prompt intervention. Quarantine staff or inspectors of consignments at the borders may be exposed to sanitary risks due to the COVID-19 pandemic. For example, it is yet unclear whether the existing biosecurity systems remained fully operational during the pandemic for an effective surveillance and management of potential biological threats to plant health or whether these systems were relaxed or restricted to some extent. In particular, it is critical to recognize that the future of global food security and safety is linked across borders. A weak biosecurity in

one country not only threatens neighbouring countries and/or continents but the entire planet. Reviewing regulations and their implementation to secure crop protection, harvests and food supply is thus critical to safeguard food systems. Application of science-based preventive actions, including quarantine measures to contain invasive pests threatening global food security and safety is critical to protect plant health.

4. Conclusions and perspectives

The COVID-19 global outbreak is a wake-up call for a joint reflection among key stakeholders who are concerned about human, veterinary and plant health, under the umbrella of the one world one health initiative. This pandemic has shown the world how adopting preventive measures is essential to secure global health from the introduction and spread of devastating pests. This applies to human health as it does to animal and plant health. More specifically to crop health, re-designing of diversified cropping systems that are less reliant on synthetic inputs will certainly help improve the resilience of cropping systems with positive impacts on soil health. Lessons learned from the COVID-19 pandemic should encourage the development of more resilient food systems that can readily face similar pandemic events in the future. Finally, although a number of impacts of the COVID-19 pandemic on crop protection have already been observed, the true impact of the pandemic remains unknown. An assessment is thus needed to measure the impact of the COVID-19 pandemic on the crop protection sector, including impacts on global plant health.

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Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: